

ELECTRONIC FUNDAMENTALS

SERVICE PRACTICES 30

TRANSISTOR APPLICATIONS

- 30-1. Transistor Amplifiers**
- 30-2. Methods of Coupling**
- 30-3. Gain Controls**
- 30-4. Power Amplifiers**
- 30-5. Oscillator Circuits**
- 30-6. Power Supplies**
- 30-7. Practical Transistor Circuits**
- 30-8. Transistor Components**
- 30-9. Servicing Transistor Circuits**

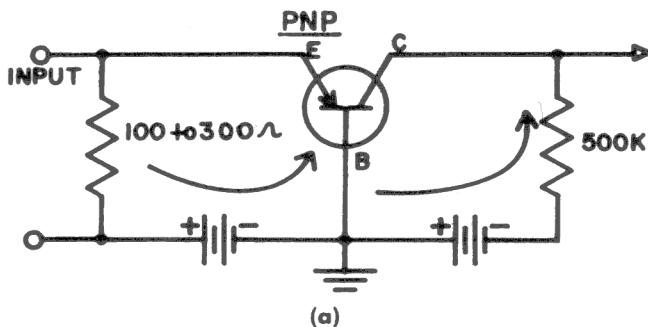


RCA INSTITUTES, INC.
A SERVICE OF RADIO CORPORATION OF AMERICA
HOME STUDY SCHOOL
350 West 4th Street, New York 14, N. Y.

Service Practices 30

30-1. TRANSISTOR AMPLIFIERS

Before undertaking the study of transistor amplifiers it should be pointed out that the manner of amplification in a transistor differs from that of a vacuum tube. It is well known that a vacuum tube is a *voltage* operated device. That is, an AC voltage is applied to the grid of the vacuum tube to control the current flow between the cathode and plate. A transistor, however, is a *current* operated device. That is, the *current* flowing in the emitter-base circuit controls the current flowing in the collector circuits. The symbols α (alpha) and/or β (beta) are used to indicate the current gain in a transistor as compared to the symbol μ (mu) to indicate voltage gain in a vacuum tube. Another important factor is the transistor input and output resistances. It is the current flowing through this resistance that determines the voltage or power gain of a transistor amplifier.



Arrows indicate direction of electron flow.

Emitter arrow indicates direction of current flow.

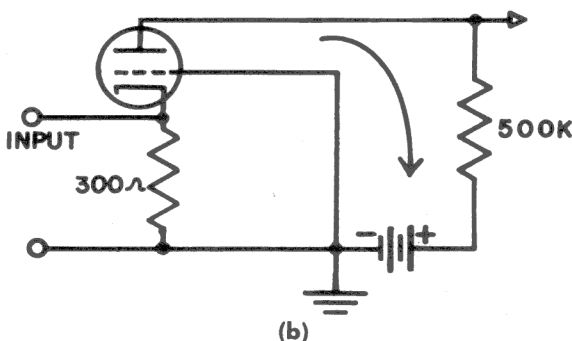


FIGURE 1

There are basically three types of transistor amplifiers; the common or grounded base, the common or grounded emitter and the common or grounded collector. The term *grounded* will be used throughout the lesson since it has greater usage in the field than the word common.

Grounded-Base Amplifier — The grounded-base amplifier circuit is similar to the grounded-grid vacuum tube amplifier which has extensive use as an RF amplifier in television tuners. A comparison of these two basic circuits is shown in Figure 1. As can be seen, the base of the transistor and the grid of the vacuum tube are grounded. The emitter is biased in the direction of greatest electron flow and the collector is biased in the direction of least electron flow. With this bias arrangement the input of the transistor has a low resistance in the order of 20 to 50 ohms and the output has a high resistance which is approximately 1 to 2 meg ohms. The current gain (or alpha) is always less than unity in this type of circuit and is usually in the order of 0.98 to 0.99. The resistance gain between base and collector is very high. The voltage gain in this type of circuit may be in the order of 1500.

The characteristic curve of a grounded-base circuit is shown in Figure 2. It can be seen

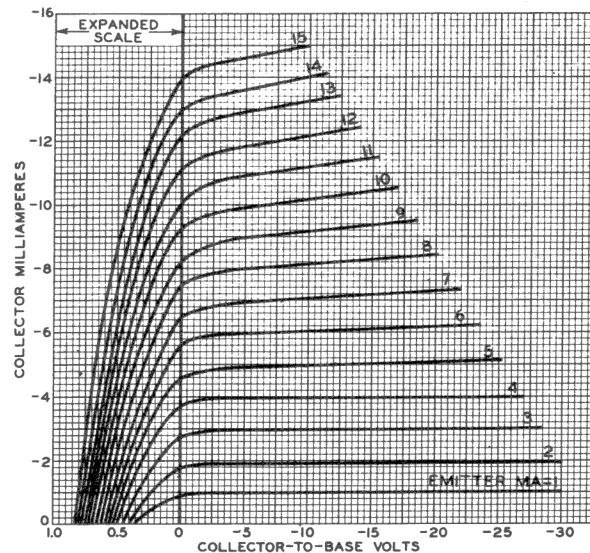


FIGURE 2

from the characteristic curve that the collector current never exceeds the emitter current. The maximum dissipation allowable for the 2N105 is 35 mw. Therefore, it is very important to maintain the proper collector voltage and emitter current so as not to exceed the maximum dissipation of the transistor. The grounded-base circuit is used when a circuit calls for a very low input impedance and very high output impedance.

The biasing arrangement of the grounded-base circuit can be simplified as shown in Figure 3. Figure 1 shows two bias supplies, one for the emitter and the other for the collector. The insertion of a resistor in the base circuit biases the emitter positive with respect to the base. Thus, by selecting the proper resistance the proper emitter current can be obtained. Signal degeneration will be introduced by this resistor, therefore, it is by-passed with a capacitor to effectively put the base at AC ground.

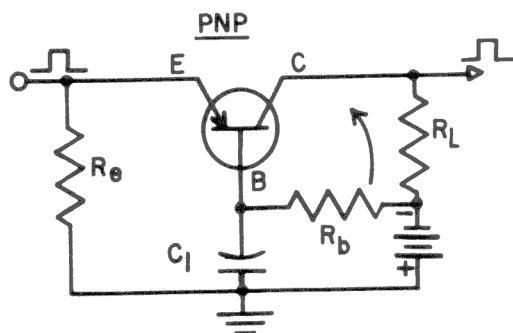


FIGURE 3

Grounded-Emitter Amplifier — The grounded-emitter amplifier is similar to the conventional, grounded-cathode, vacuum tube amplifier. The signal is applied to the base of the transistor, whereas in the vacuum tube the grid is the driven element. A comparison between the transistor and vacuum tube circuits is shown in Figure 4.

As in the case of the grounded-base amplifier, the emitter is biased in the direction of greatest current flow and the collector is biased in the direction of least current flow. The resistance of the input circuit is normally in the range of 1,000 to 2,000 ohms, however it may be as low as 100 ohms or as high as 10,000 ohms. The output resistance is normally about 50,000 ohms, however, it may be as low as 5,000 ohms and as high as 500,000 ohms.

The characteristic curve of the grounded emitter circuit is shown in Figure 5. This

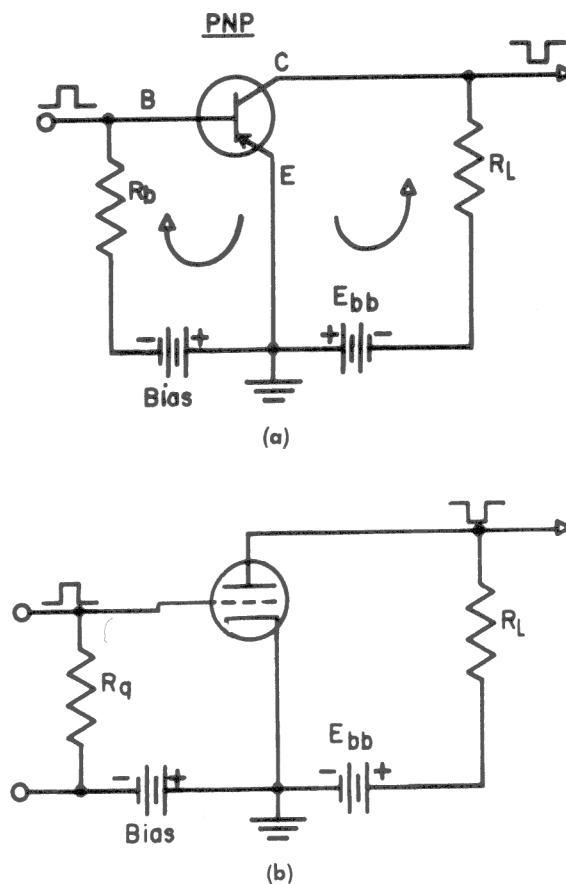
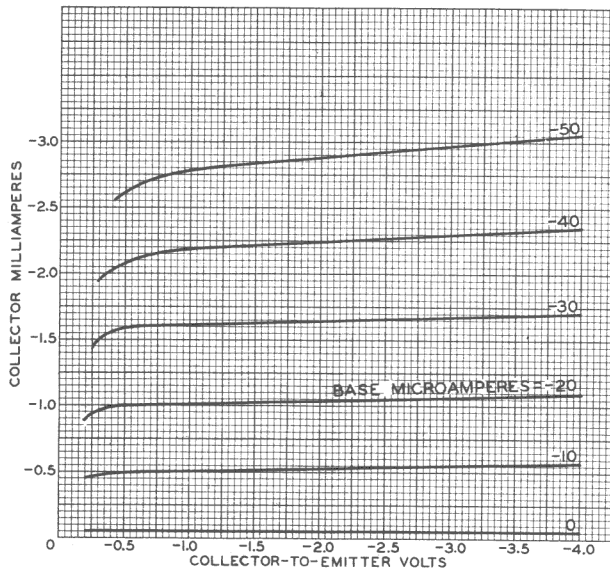
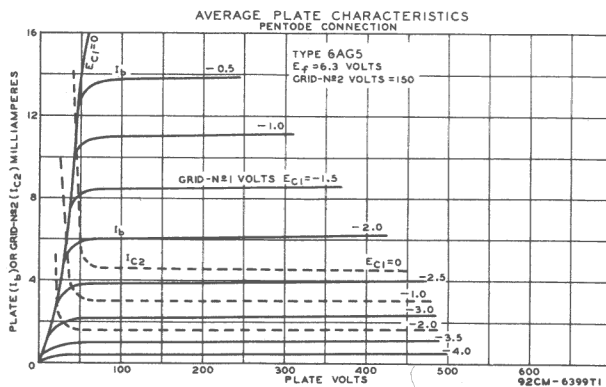


FIGURE 4

curve is for the RCA Type 2N105, P-N-P, junction transistor and is compared with the I_p - E_p curve of an RCA Type 6AG5 vacuum tube. The major difference lies in the fact that in a transistor the collector current is controlled by the emitter current, whereas, the vacuum tube plate current is controlled by the grid to cathode bias voltage. Aside from this, the curves are used in a similar manner. From the characteristic curve shown in Figure 5(a), it can be seen that for a very small change in base current, a relatively large change in collector current is possible. For example, as shown in Figure 5(a), with a collector voltage of minus 4 volts, a change of base current from 20 to 30 micro-amperes produces a change of collector current from 1.1 to 1.7 milli-amperes. We can say then, that a 10 micro-ampere change in base current produces a 600 micro-ampere change in collector current; thus, a current gain is realized under these operating conditions for the RCA Type 2N105 transistor. This current gain is called the *beta* (β) gain between the base and collector as compared to the *alpha* (α) gain



(a)



(b)

FIGURE 5

between the emitter and collector in the grounded-base amplifier.

Power gains of 42 db or approximately 10,000 times can be realized with this circuit arrangement. The voltage gain of this circuit arrangement is the same as that of the grounded-base connection, but the current gain is considerably higher. Due to this increase of gain over the grounded-base connection, this circuit is popular for many circuit designs.

As with the grounded cathode vacuum tube circuit, a voltage reversal takes place between base and collector. A positive signal at the base opposes the bias voltage causing a smaller base current, thus decreasing the collector current. The decrease in collector current causes the collector to become more negative. Therefore, a positive signal at the base develops a negative signal at the collector.

Various methods have been established for biasing the base in the grounded-emitter circuit. In Figure 4, two separate bias supplies

are used. It can be noted, however, that both the base and collector are negative with respect to the emitter. Therefore, the bias arrangement can be simplified as shown in Figure 6. This method can be called *fixed bias*.

The base current can be established by choosing the proper value of base resistance R_b . For example, if a base current of 30 microamperes is desired:

$$R_b = \frac{E_{bb}}{I_b}$$

$$= \frac{6 \text{ volts}}{30 \times 10^{-6} \text{ amps}}$$

$$= 200 \text{ k ohms}$$

This value of base resistance includes the internal emitter to base resistance, however, this represents only a few hundred ohms and the internal resistance can normally be neglected.

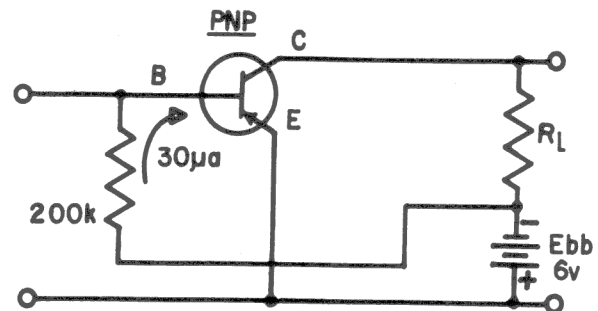


FIGURE 6

Fixed bias is not the most satisfactory method of biasing the base. Due to variations between transistor units and their sensitivity to temperature changes, it is difficult to maintain a critical base current. One method of partially overcoming this problem is to tie the base resistor directly to the collector as shown in Figure 7. This arrangement provides degeneration in a form of *automatic control* of the base bias and can be called *self bias*. To determine the value of R_b , the supply voltage

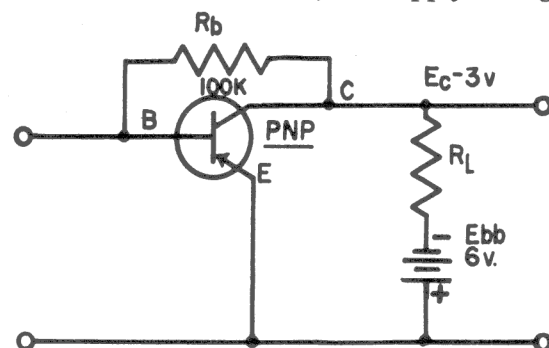


FIGURE 7

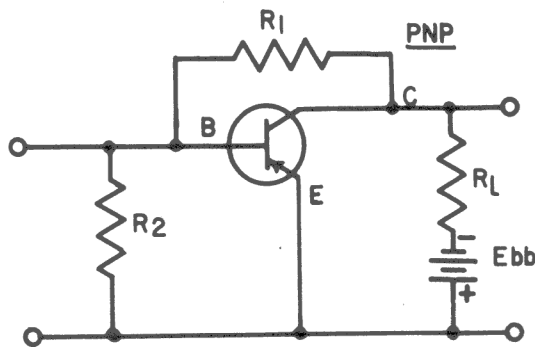


FIGURE 8

(E_{bb}) is replaced by the collector voltage (E_c) in the previous formula:

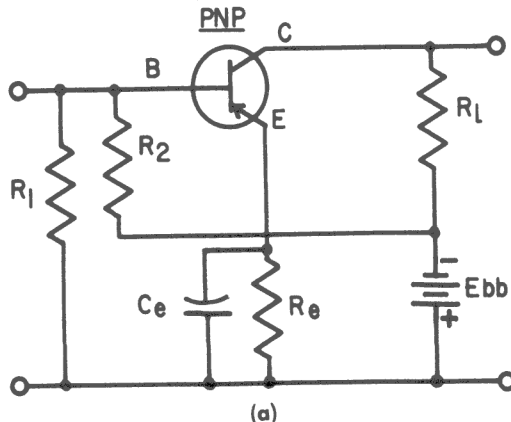
$$R_b = \frac{E_c}{I_b}$$

$$= \frac{3 \text{ volts}}{30 \times 10^{-6} \text{ amps}}$$

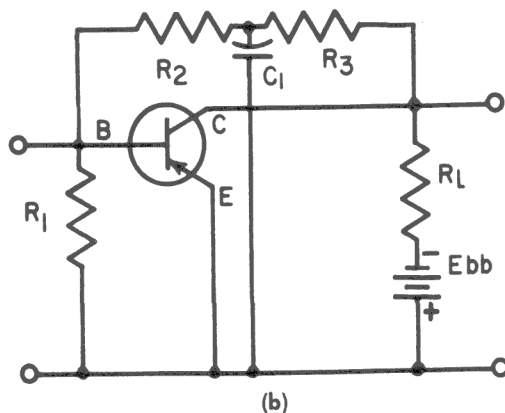
$$= 100 \text{ k ohms}$$

This method of self bias causes AC negative feedback which, although it overcomes many of the disadvantages of fixed bias, reduces the effective gain of the amplifier.

Both fixed and self bias can be used to provide even better circuit stability. This method is illustrated in Figure 8. Here a voltage di-



(a)



(b)

FIGURE 9

vider composed of R_1 and R_2 biases the base negative with respect to the emitter. Bleeder current through the voltage divider fixes a bias at the base. However, any change in collector voltage due to a change in emitter current will automatically change the base bias. This circuit is commonly used due to its inherent stability.

To minimize loss of gain either of the two circuits shown in Figure 9 may be used. In Figure 9(a) a resistor is added to the emitter circuit and R_2 is returned to the negative terminal of the battery instead of the collector. The emitter resistor (R_e) provides additional stability and is usually $\frac{1}{5}$ to $\frac{1}{10}$ the value of R_1 . To prevent emitter degeneration, capacitor C_e is added. The value of this capacitor is usually about 50 mfd; however, the value may be much higher depending, among other things, upon the lowest frequency to be amplified. The emitter resistor in this case is similar to the cathode resistor in an electron tube circuit.

Another method is shown in Figure 9(b). Here the voltage divider is split and all AC variations are bypassed by capacitor C_1 . The value of R_1 is usually 5 to 10 times the value of R_2 . The total resistance of R_2 and R_3 should equal the resistance of R_1 shown in Figure 8. In some circuit applications a combination of Figures 9(a) and 9(b) may be used. In other cases a bypassed emitter resistor may be added to the circuit of Figure 8. Voltage gain and circuit stability are usually the determining factors when selecting the proper circuit.

Grounded-Collector Amplifier—The grounded-collector amplifier circuit is similar to the vacuum tube cathode follower circuit. Both circuits are illustrated in Figure 10. The input impedance (resistance and reactance) of the transistor circuit is high and the output impedance is low, being similar to the vacuum tube circuit. The output impedance of the transistor circuit is dependent on the input impedance, however, this is not the case in electron tube circuits. The voltage gain is less than unity and the power gain of the stage is usually lower than either the grounded emitter or grounded base stages. The circuit is mainly used as an impedance matching device.

As in the case of the grounded base amplifier there is no phase reversal of the signal between the input and output. The same is true in the cathode-follower vacuum tube circuit and the grounded grid tube circuit.

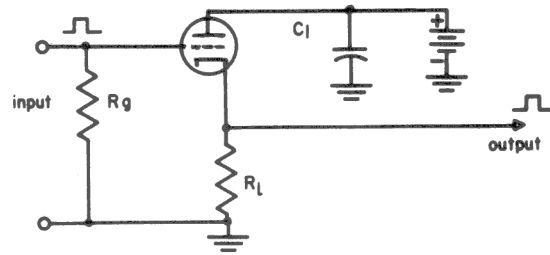
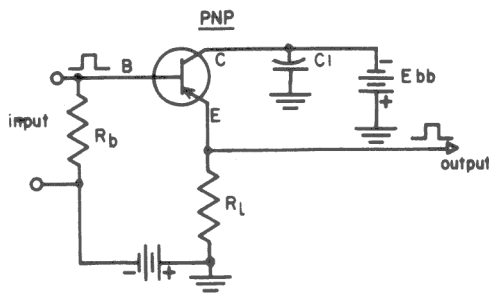


FIGURE 10

30-2. METHODS OF COUPLING

The basic methods of coupling transistor stages are similar to those used in vacuum tube circuits. The major difference lies in the fact that the input and output resistance of transistors as compared to vacuum tubes vary widely. These resistances depend on the type transistor used and the operating conditions. Also a change in input or output load resistance reflects into the input or output, whichever the case may be. For example, as the load resistance increases, the input resistance decreases. This is not generally true with vacuum tubes since changes in the plate load do not normally reflect into the grid circuit. In some cases, however, plate to grid capacitance becomes a factor and plate loading will affect the input impedance of an electron tube circuit.

The coupling requirements for transistors can be met by various methods, such as, transformer, R/C , impedance and direct coupling. Each of these methods will be discussed.

Transformer Coupling—The method of transformer coupling transistor stages is illustrated in Figure 11. As can be seen, this grounded emitter circuit employs fixed and self bias and an emitter resistor (R_e) for stabilization. The biggest advantage of this circuit is that the input and output impedance of the transistor can be matched for maximum power gain. A step down transformer, T_1 , is used from the collector of the preceding stage to the base of the following grounded emitter stage as shown in Figure 11. Due to this step down it would seem that a voltage loss appears across the secondary of T_1 and would defeat our purpose. However, it must be remembered that a transistor is a *current operated* device, not a voltage operated device such as the vacuum tube. This step down provides best power transfer and the change in base current, due to the presence of the signal, activates transistor ac-

tion and a power gain can be measured across the primary of T_2 . This step down can be compared to the output stage of an audio amplifier, where a step down transformer is required to drive a loudspeaker, which is a current operated device. The purpose of the transformer is usually for maximum power transfer.

The circuit components include a voltage divider (R_1 and R_2) which provides the proper bias. The voltage divider is bypassed by C_1 to avoid signal attenuation. The emitter resistor (R_e) is the stabilizing resistor which allows variations of the transistor and circuit elements to be absorbed automatically without adverse effects. This resistor (R_e) is bypassed by C_2 to prevent loss of gain due to degeneration. The supply voltage E_{bb} is also bypassed to prevent feedback due to possible AC signal voltages being developed across the power supply. Capacitors C_1 and C_2 may be replaced by a single capacitor connected between the emitter and the bottom of the secondary of T_1 .

Transformer coupling in *IF* stages can present problems in design. Basically, the *IF* transformer is used to select the desired signal frequency and has a band width capable of passing the sidebands of the desired signal fre-

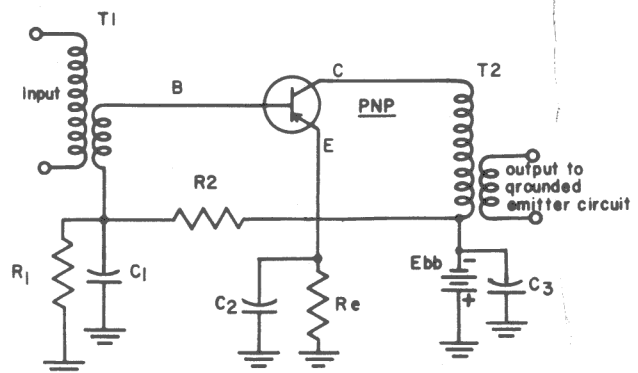


FIGURE 11

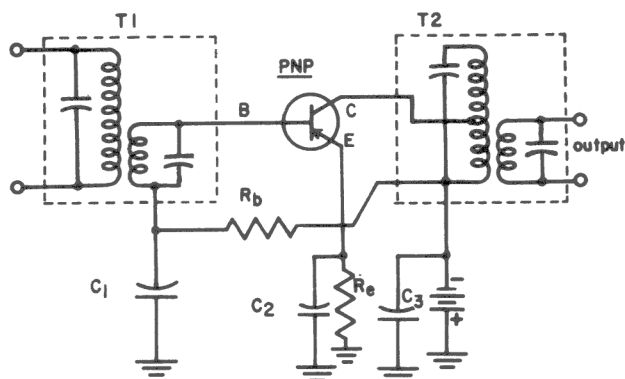


FIGURE 12

quency but rejects adjacent signals. This means the Q of the IF transformer must be carefully specified and maintained. In the case of vacuum tube circuits the output resistance of an amplifier is sufficiently high that adjusting the transformer to have the proper Q is no problem. If the output resistance is low (100K or under) the Q of the transformer is lowered, possibly causing poor selectivity. This is the case when using transistor amplifiers. A typical output resistance of a transistor radio IF stage (455KC) is approximately 25K ohms. If the collector is shunted across the entire primary of transformer T_2 , as shown in Figure 11, the selectivity will be seriously affected due to the output resistance of the transistor reducing the Q of T_2 . To overcome this problem, the circuit is connected as shown in Figure 12. By selecting the proper tap on T_2 for the collector connection, the Q of the circuit can be satisfied as well as properly matching the output resistance of the transistor.

An exact match is not always desirable since feedback is also a major problem in transformer design. In some cases neutralization is incorpo-

rated as was done in old triode IF amplifiers. In other circuits the primary is not tapped for the collector connection. By selecting the proper L/C ratio the correct Q can be maintained, however, neutralization may be necessary. Also some circuits use a center tapped secondary in order to balance the feedback currents. In this case no neutralization is necessary.

R/C Coupling—Transformer coupling can be used to advantage in IF strips or any RF application where selectivity is required. They are also used in large signal audio circuits such as drivers and output stages. However, R/C coupling is desirable where low level audio signals are involved since transformers are more susceptible to hum pick-up and also take up space. Figure 13 illustrates a two stage R/C coupled circuit. The method of bias is similar to that used in transformer coupling. The major additions are R_L (collector load) and C_c (coupling capacitor). The coupling capacitor (C_c) must be made very large (2 to 10 mfd) due to the small output and input resistances involved.

It should be noted that electrolytic capacitors are used for coupling whereas they are not used in electron tube circuits. Therefore, polarity should be observed or damage to the capacitors and possibly to the transistor may occur. Leakage current is not as critical in transistor circuits as in electron tube circuits.

When cascading R/C coupled amplifiers as shown in Figure 13, it is necessary to decouple one or more stages in order to prevent feedback. One method of decoupling is illustrated in Figure 14. This is accomplished by inserting resistor R_i in series with the base resistor and bypassing R_i by means of capacitor

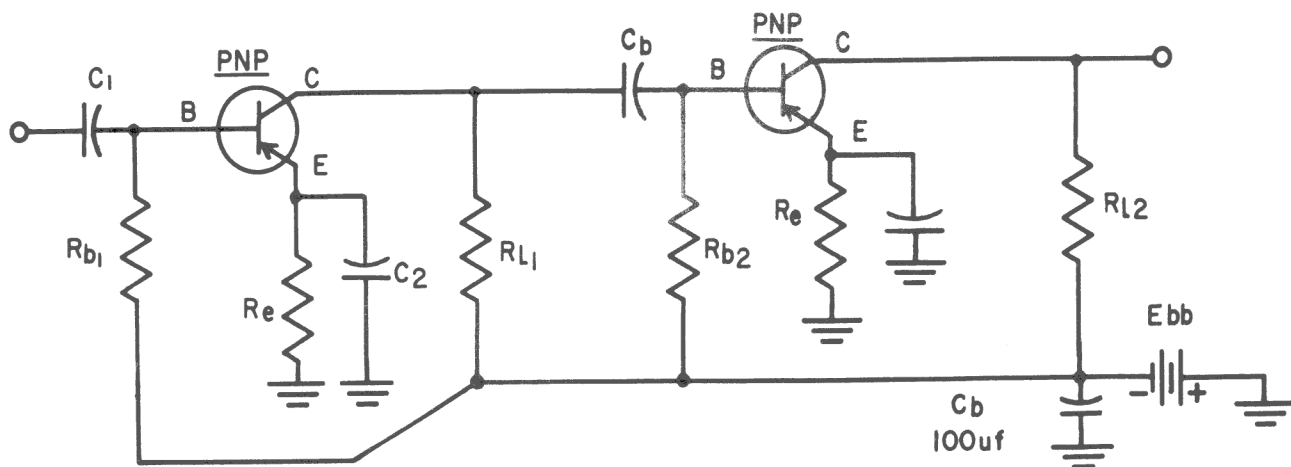


FIGURE 13

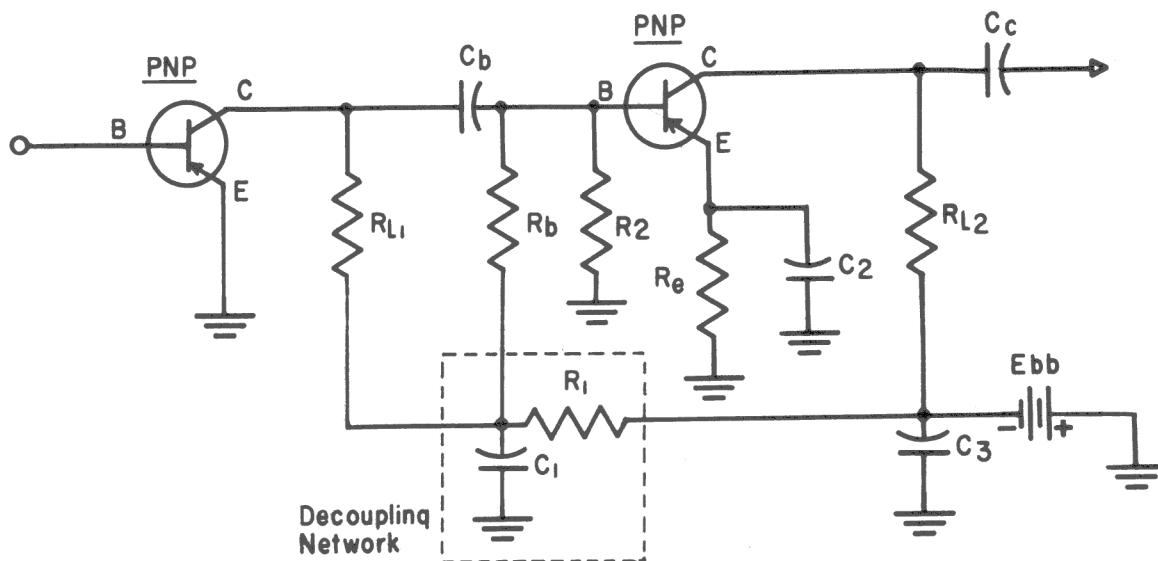


FIGURE 14

C_1 . The R_1C_1 time constant should be adjusted to insure that the lowest frequency to be amplified is adequately bypassed. Generally the value of R_1 must be kept small so that the supply voltage is not drastically reduced to the previous stages. Therefore, the value of C_1 must be very large, usually 100 mfd or larger.

Impedance Coupling — Impedance coupling is similar to R/C coupling. The major difference lies in the fact that inductances are used to replace the load resistors in Figure 5. This type of coupling may be used for circuit applications above audio frequencies. Resistors R_1 and R_2 are still necessary in order to provide the proper emitter-base bias.

Both series and shunt peaking can be accomplished in this type of coupling. Peaking coils similar to those associated with vacuum tube circuits in television receivers may be used in transistor video amplifiers.

Direct Coupling—Direct coupling is used generally where cost is a factor. However, it is also used where partial DC restoration is required in television receivers and where the DC component must be amplified. A direct coupled amplifier is shown in Figure 16. In cases where the DC component must be retained in whole the capacitors must be eliminated. As can be seen in Figure 16, resistor R_1 serves as both the collector load of Q_1 and the bias resistor of Q_2 .

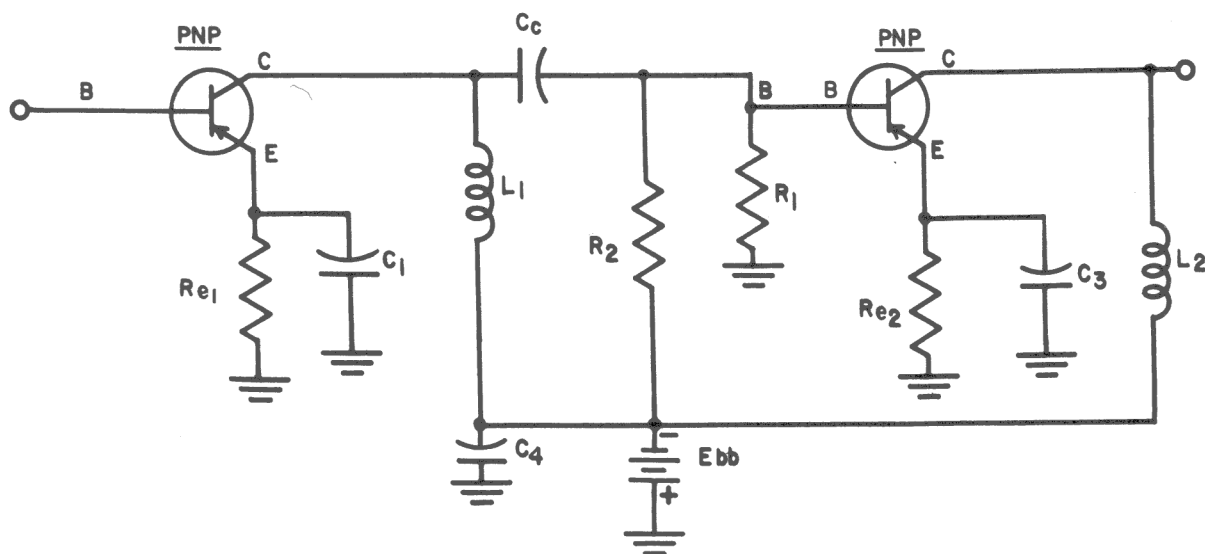


FIGURE 15

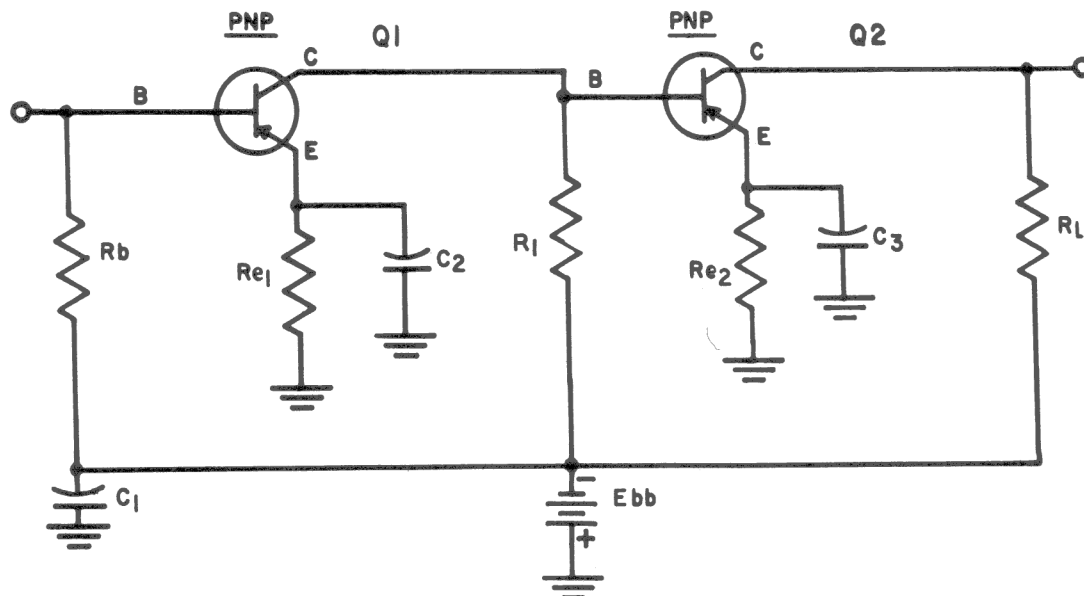


FIGURE 16

30-3. GAIN CONTROL

As in vacuum tube circuits, volume controls must be used in transistor audio amplifiers to provide means for suitable audio level adjustment by the listener. Although these controls are generally associated with R/C coupled amplifiers, they are also used where transformer or direct coupled circuits are involved.

A volume control circuit is illustrated in Figure 17. The circuit includes the volume control and the 1st audio amplifier. The capacitor C_2 prevents the volume control R_2 from changing the DC operating point of the previous stage. Capacitor C_3 prevents the base current from flowing through the volume control. Resistors R_3 and R_4 provide the base bias. The base must be negative with respect to the emitter for PNP transistor operation. The

coupling capacitors C_2 and C_3 must be large in value due to the low circuit impedances involved.

Where transformer coupling is used, a circuit as shown in Figure 18 may be used. The resistance of the volume control R_1 should be about 2 to 3 times the impedance of the secondary of the coupling transformer to prevent excessive loading.

30-4. POWER AMPLIFIERS

Transistor power amplifiers can be divided into two basic types: single ended and push-pull. Also, as in vacuum tube circuits, transistor power amplifiers can be classified by their modes of operation, such as, Class A amplifiers, Class B amplifiers, etc.

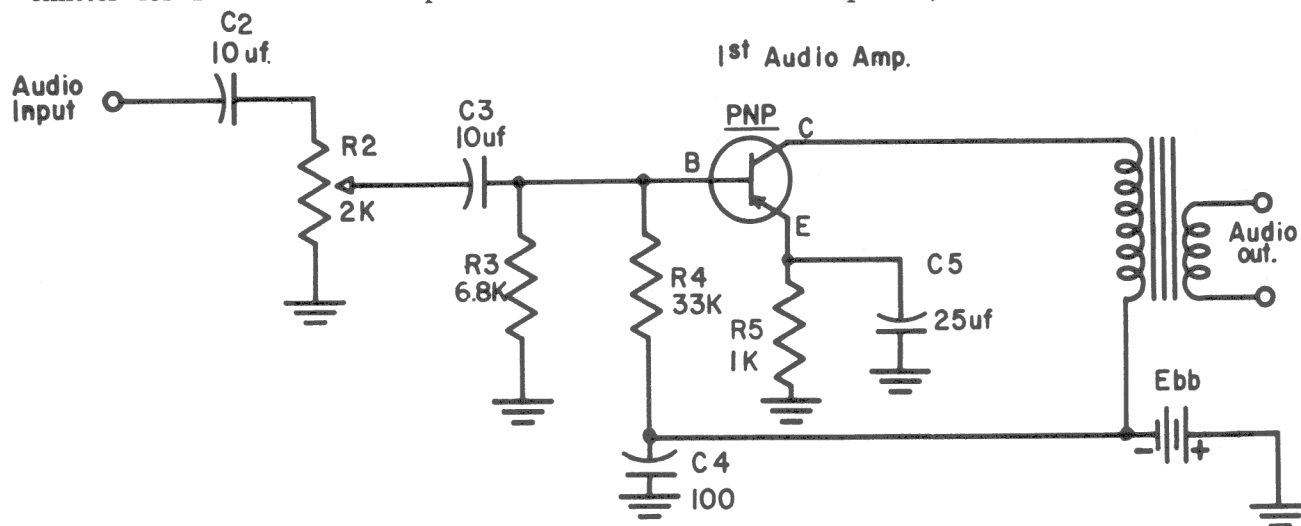


FIGURE 17

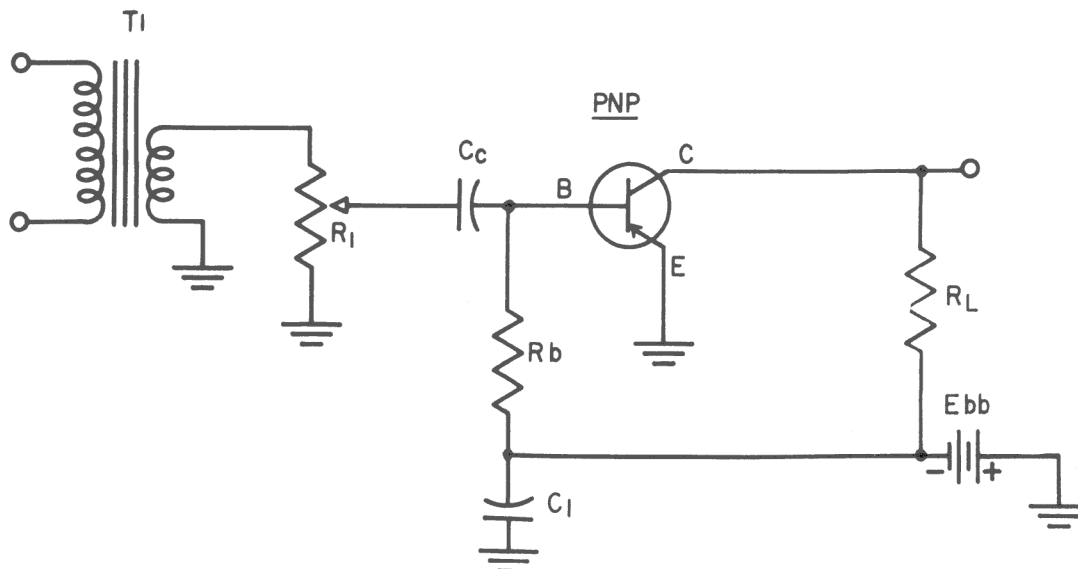


FIGURE 18

Class A Amplifiers—A typical class A, single ended, power amplifier is shown in Figure 19. The base-emitter circuit is biased in the direction of greater current flow by the bleeder arrangement of R_1 and R_2 . This causes the emitter to be positive with respect to the base. The emitter current is stabilized by R_3 and the AC component is bypassed by capacitor C_1 . Since this amplifier is used to drive a loudspeaker, a matching transformer, T_1 , must be used. Capacitor C_2 is often used to limit the bandwidth to prevent high frequency distortion.

This type of circuit is limited as to power output. The circuit is arranged so that the collector current with no input signal is 11 ma. and the collector to emitter voltage is 6 volts. This means the transistor is dissipating 66 milliwatts. Since this exceeds the maximum dissipation of a 2N109 transistor a "heat sink" must be used to prevent transistor destruction. The case of the transistor is usually connected to a large metal object such as a speaker frame by means of a heavy braided metal strap.

A load line can be constructed as shown in Figure 20. The supply voltage is 9 volts,

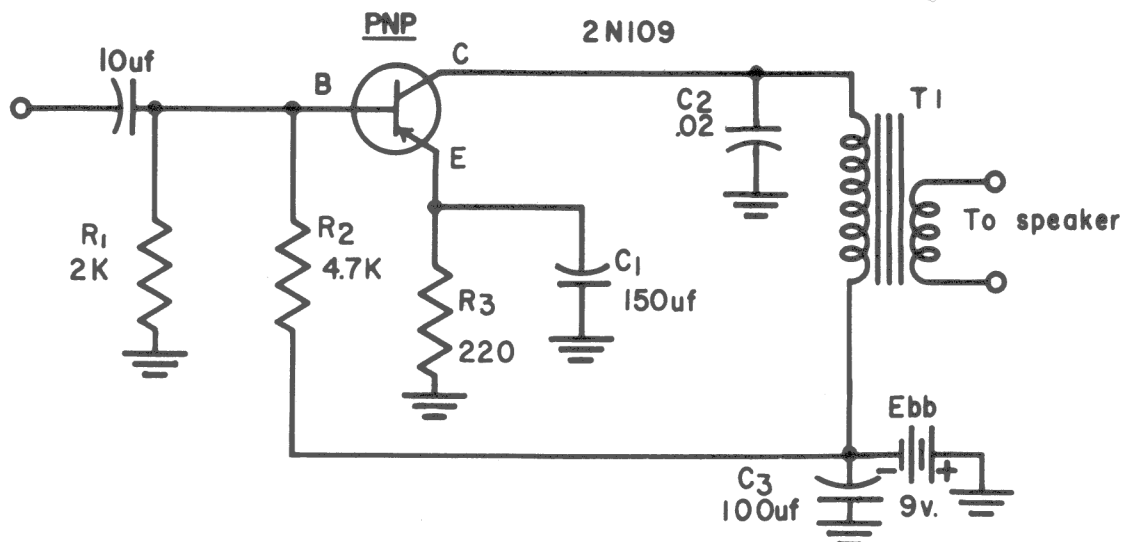


FIGURE 19

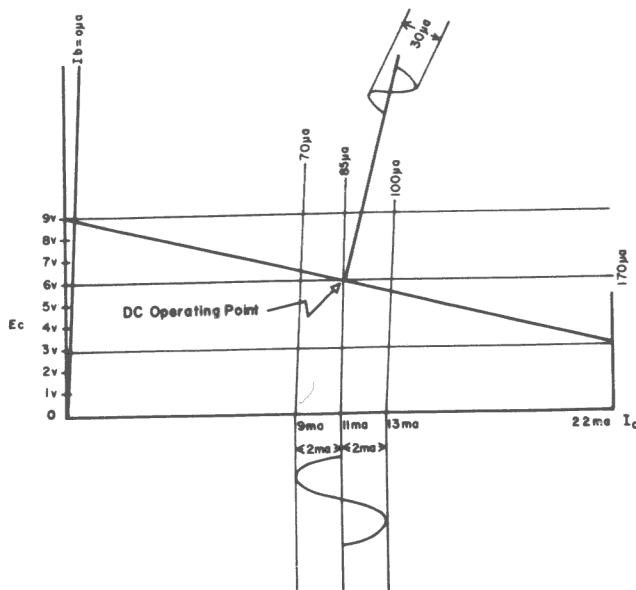


FIGURE 20

therefore, the collector voltage (V_{ce}) when the collector current (I_c) is zero is also 9 volts. The load line is drawn from the 9 volt point through the DC operating point of the I_c - E_c curve. As can be seen the output will be linear from zero base current (I_b) to 170 microamps of I_b . Any greater swing in base current will cause distortion of the output signal. Therefore, the maximum undistorted output can be calculated as follows:

$$\begin{aligned} \text{Power Out.} &= \frac{V_{ce} \text{ (peak to peak)} \times I_c \text{ (peak to peak)}}{8} \\ &= \frac{9.3 \text{ volts} \times 22 \times 10^{-3} \text{ ma}}{8} \\ &= \frac{6 \times 22 \times 10^{-3}}{8} \\ &= 16.5 \text{ milliwatts} \end{aligned}$$

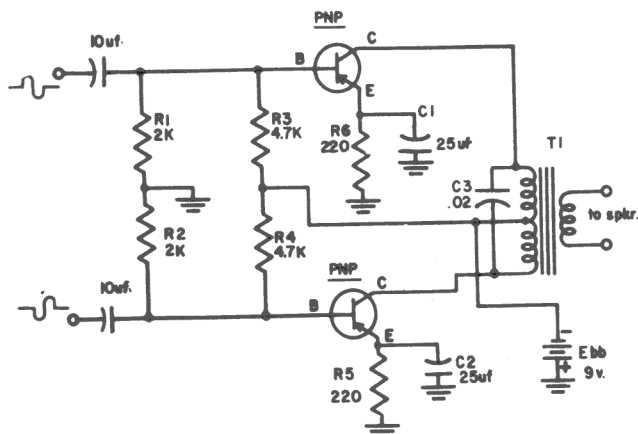


FIGURE 21

A greater output can be obtained, but, it will be distorted due to clipping of the input signal.

In order to provide a higher power output with less distortion, a push-pull circuit arrangement should be used. A Class A push-pull audio amplifier is illustrated in Figure 21. A similarity can be noted between the single ended and push-pull circuits. Actually identical components are used, the difference being that the two transistors in the push-pull stage are driven 180 degrees out of phase.

The chief advantage of this circuit is one of less distortion at greater power outputs.

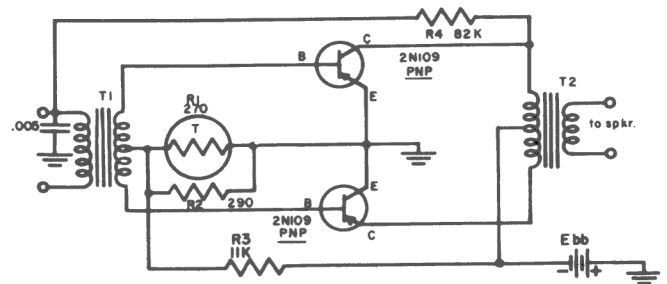


FIGURE 22

Class B Amplifiers—One of the disadvantages of a transistor Class A amplifier is that collector current flows at all times. The transistor dissipation, therefore, is high even when no AC signal is present. The dissipation can be greatly reduced by the use of an emitter-base bias such that very little collector current flows when no input signal is present. This type of operation is called Class B. When PNP transistors are operated under Class B conditions collector current flows only during negative signal excursions; when NPN transistors are used, collector current flows only during positive signal excursions. The resulting distortion is minimized by the use of two transistors connected in push-pull.

A Class B push-pull audio amplifier is illustrated in Figure 22. The base-emitter circuit is biased near collector cutoff so that very little collector power is dissipated under no signal conditions. Ideally, the transistors would be biased to cutoff and no power would be dissipated under no signal conditions. However, at low signal inputs the resulting signal would be distorted as shown in Figure 23(a). This is known as *cross-over distortion*. By biasing the transistors so that a small collector current flows at all times the greater portion of this distortion can be eliminated. Figure 23(b)

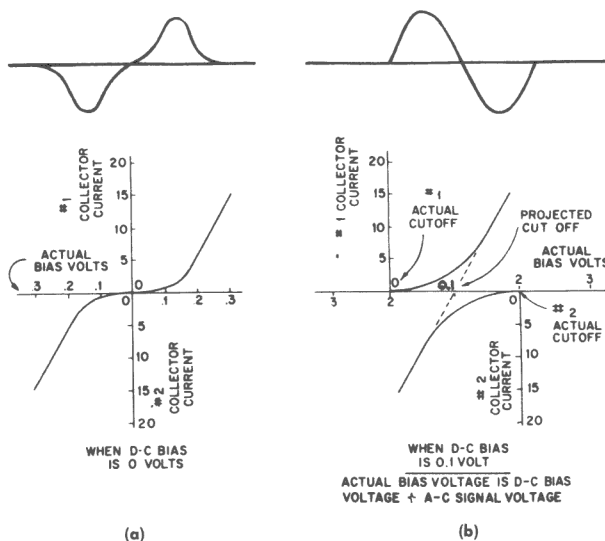


FIGURE 25

shows how the coincidence of the projected cutoff points corrects this distortion. Any residual distortion can be minimized by the use of negative feedback. In Figure 22 this feedback is provided by resistor R_4 .

Resistors R_1 , R_2 , and R_3 form a bleeder network which provides proper bias for the transistors. To minimize distortion at low signal levels and prevent thermal destruction of the transistors the characteristics of this network must be very carefully chosen. It was pointed out earlier that the collector current, collector dissipation, and DC operating point of a transistor vary with the ambient temperature. To minimize the effects of these variations a thermistor (R_1) is used in the biasing network. When the ambient temperature increases the resistance of the thermistor decreases, and vice versa, so as to maintain constant voltage across the biasing network. Since the bias voltage controls the emitter and collector currents, the thermistor stabilizes the DC operating level over a wide range of ambient temperature.

30-5. OSCILLATOR CIRCUITS

In general, transistor oscillators function in the same manner as electron tube oscillators. To sustain oscillation an amplifying device having a gain greater than 1 is required. The output of the amplifier is fed back in phase with the input signal with sufficient amplitude to overcome circuit losses. Two basic types of feedback will be discussed. One type uses tuned reactive circuits and the other type uses R/C networks.

Tuned L/C Oscillators—A transistor oscillator and its vacuum tube equivalent are illustrated in Figure 24. The electron tube circuit in Figure 24(a) is a typical Meissner oscillator. The plate signal is fed back in phase with the grid signal in order to sustain oscillations. The frequency can be varied by the variable capacitor C_1 . This type of oscillator can be adjusted to produce continuous sine waves or be self-quenching by choice of the proper time constant for C_c and R_g .

The transistor circuit shown in Figure 24(b) is just as versatile. For sine wave output resistor R_1 (base resistor) is adjusted for enough bias to prevent the transistor from cutting off on positive voltage swings. The circuit can be made self-quenching by readjustment of R_1 .

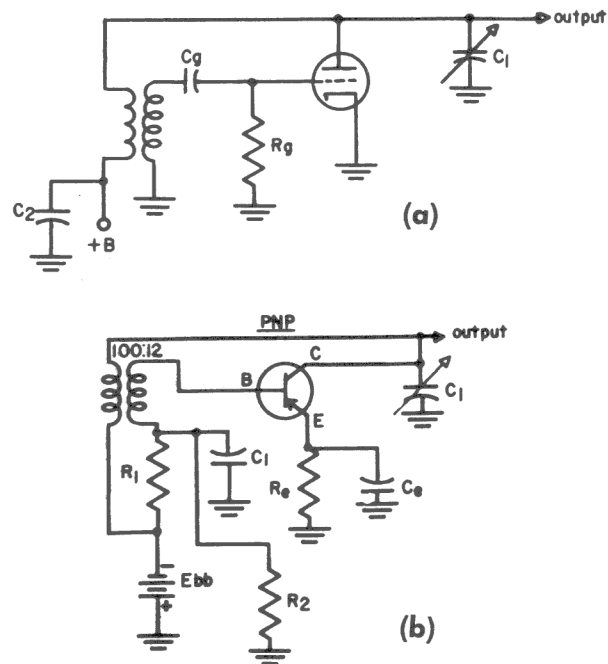


FIGURE 24

Since the transistor is a current operated device, a voltage step down is used between the collector and base. Thus, a small current change in the collector causes a large current change in the base. This action sustains oscillations by overcoming circuit losses. A stabilizing resistor R_e is normally included in the emitter circuit to compensate for variations between production transistors. Resistors R_1 and R_2 provide a low impedance bias source. To prevent self-quenching the time constant of R_1 , R_2 and C_1 is made long compared to that of R_e and C_e . R_2 and C_e have a function

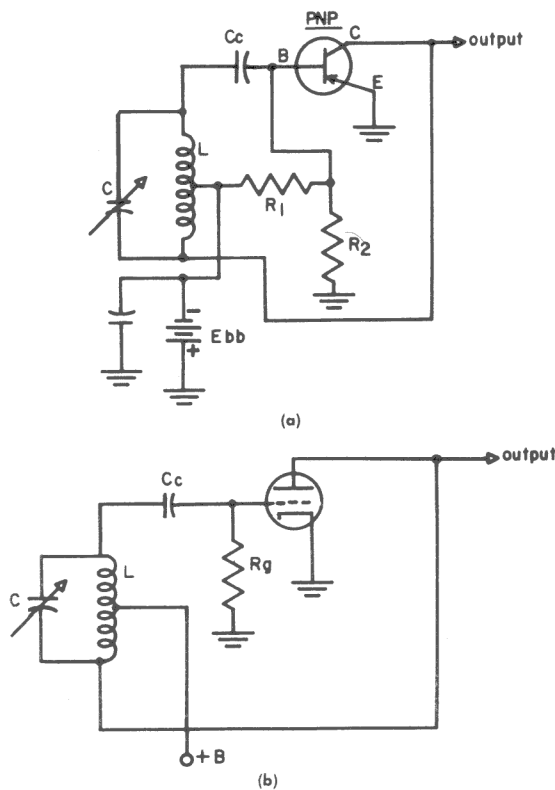
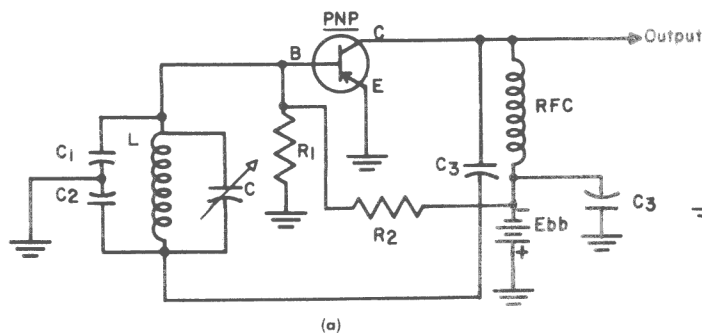


FIGURE 25

similar to that of C_g and R_g in the electron tube circuit. Therefore, the emitter time constant is an important consideration.

Another common type of oscillator known as the *Hartley* is illustrated in Figure 25 along with its vacuum tube counterpart. The L/C tuned circuit is common to both the input and output circuits. Voltage from the collector circuit is developed across a portion of L , inducing a current of the proper phase into the base circuit in order to maintain oscillation. Again since the transistor is a current operated device, there is a voltage step down from collector to base. However, there is a *current* step up to meet the requirement for the oscillator mode of operation.



The *Colpitts* oscillator is another widely used circuit. The transistor circuit and its vacuum tube counterpart are illustrated in Figure 26. As in the Hartley circuit the tuned circuit is common to both the input and output. Capacitors C_1 and C_2 split the signal to provide the proper feedback in order to maintain oscillation. Resistors R_1 and R_2 of the transistor circuit provide the proper bias between the base and emitter.

In servicing these types of transistor oscillators the base voltage waveform can be checked with an oscilloscope to indicate the amplitude of the AC voltage. This waveform is not always a pure sine wave. For RF conversion in superheterodyne receivers a pure sine wave is not absolutely necessary. Therefore, for stability reasons in some transistor circuits the amplitude of the sine wave will appear somewhat compressed. Actual VTVM base to emitter voltage measurements are impractical since the voltage difference is very small. Care must be taken not to load the circuit. A medium to high impedance probe is generally required.

R/C Oscillator—A transistor R/C (multivibrator) oscillator circuit is shown in Figure 27. As can be seen from the circuit it is very similar to an electron tube circuit. Components C_{b1} , C_{b2} , R_{b1} and R_{b2} form a time constant which roughly fixes the operating frequency. However, the collector current cutoff point (I_{co}) and the emitter current cutoff point (I_{eo}) also must be considered. The output waveform is essentially a square wave.

30-6. POWER SUPPLIES

The power requirements of most transistor circuits, such as found in transistor radios, are very small as compared to vacuum tube circuits, and often allow economical and practical operation with batteries. The power require-

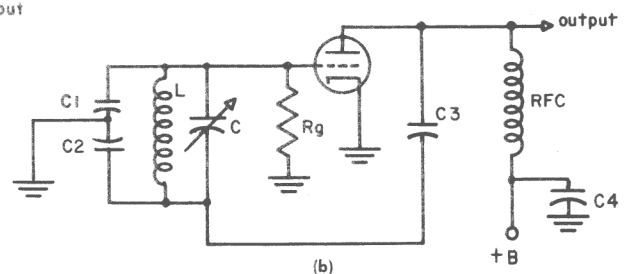


FIGURE 26

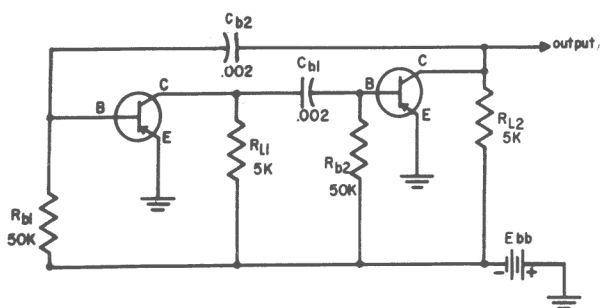


FIGURE 27

ments of some transistor circuits are so small that the operating battery life will nearly equal its normal shelf life. The familiar zinc-carbon batteries as used in vacuum tube portable radio receivers and flashlights may be used as a power source.

Another type of battery that can be used as



FIGURE 28

a power source is the mercury cell. These cells offer several advantages over the zinc-carbon type. They are more stable and rugged, both mechanically and electrically. They have a

much longer shelf life and a greater current capacity than similar sized zinc-carbon batteries. Thus, they are well suited to the design of sub-miniature equipment.

The RCA type VS300 nine (9) volt mercury cell battery is illustrated in Figure 28. It is composed of seven individual mercury cells stacked together. Each mercury cell has a voltage output of approximately 1.4 volts. One of the cells is illustrated in Figure 29 showing the internal construction. (Electrical energy

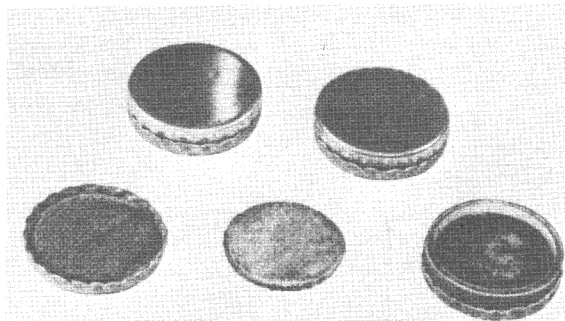


FIGURE 29

is produced by an electro-chemical reaction between amalgamated zinc powder and mercuric oxide, with potassium hydroxide solution used as an electrolyte. A layer of cotton saturated with the electrolyte separates the zinc and the mercuric oxide.)

The case of the mercury cell is made of steel. Due to the high stability of the chemicals and the inactive case material, there is no internal cell reaction until electrical energy is drawn from the cell. The shelf-life, therefore, is extremely long.

In more complex transistor circuits, intended for continuous operation, it is imprac-

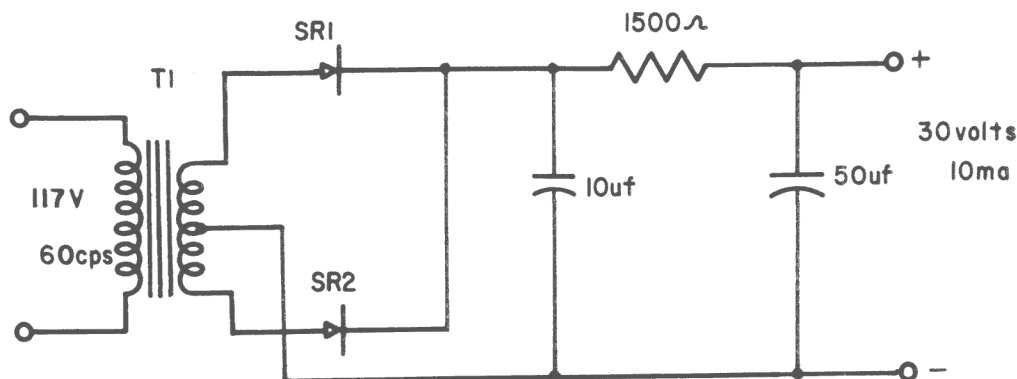


FIGURE 30

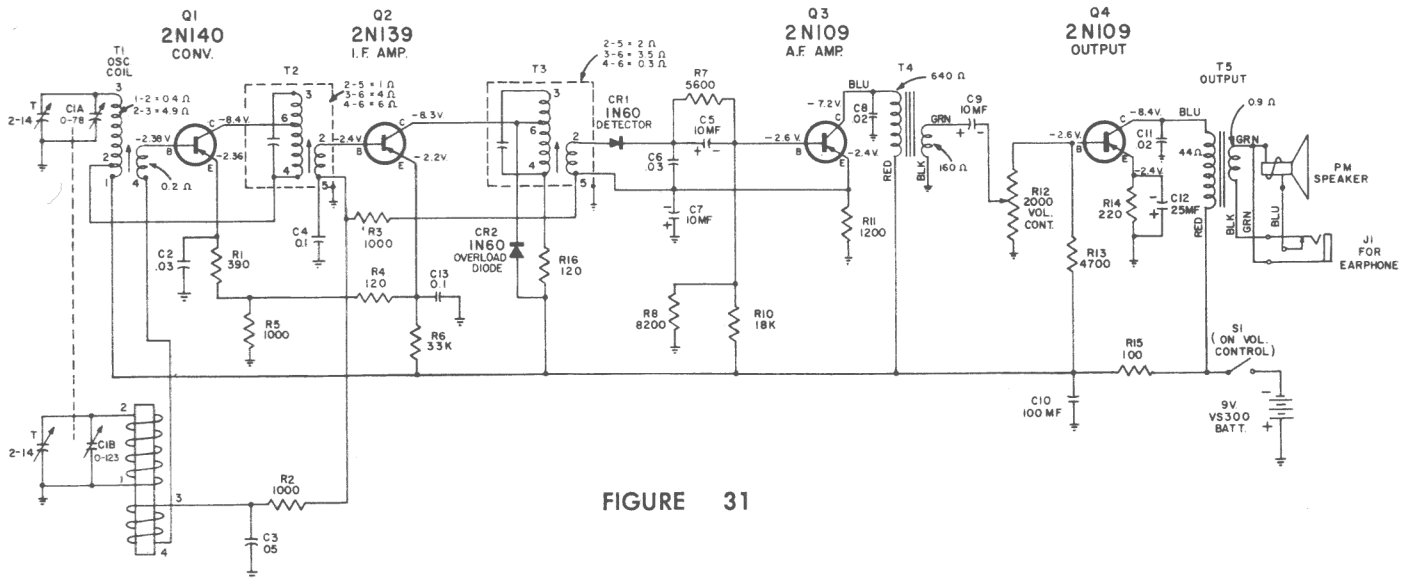


FIGURE 31

tical to use battery power supplies. AC power supplies are used in these applications. A transistor power supply is illustrated in Figure 30. The circuit is a full-wave rectifier with an R/C filter. This particular circuit supplies 30 volts at 10 ma of current drain.

30-7. PRACTICAL TRANSISTOR CIRCUITS

Portable radios were the first to use transistors for entertainment type equipment. Transistors are also employed in automobile radios, computers, television receivers, etc. A discussion of several circuits which have been used in practical applications or have been developed experimentally will follow.

Pocket Radio—The circuit diagram of an extremely compact pocket radio is presented in Figure 31. This circuit covers the AM broadcast band from 550 to 1600 KC. The IF frequency is 455 KC, and the undistorted audio output is 25 milliwatts. A ferrite loop antenna is used to capture the signal energy which is transformer coupled to a low impedance secondary winding. The current developed in this secondary winding flows in the base-emitter circuit of Q_1 (2N140). Q_1 serves a dual purpose as an oscillator and converter. Transformer T_1 , combined with $C1A$, tuning capacitor, forms the oscillator tank circuit. An AC regenerative voltage is fed back from the

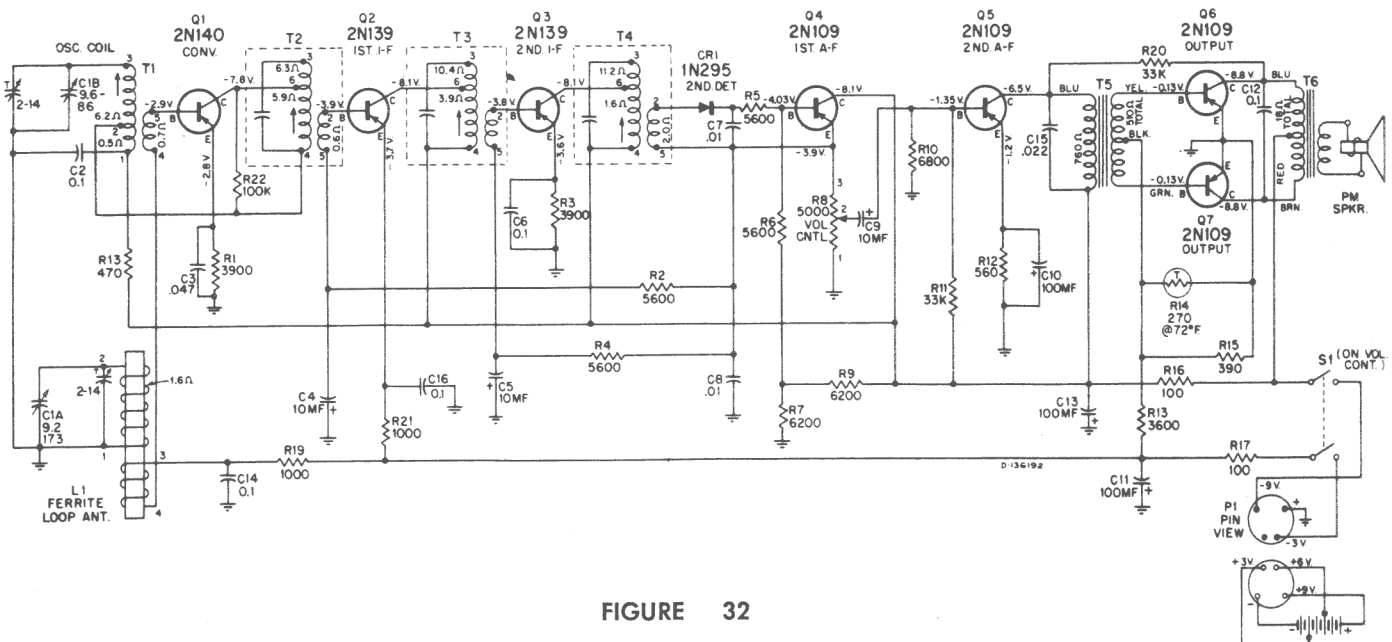


FIGURE 32

collector circuit to the primary of T_1 . The secondary is a low impedance winding causing the feedback current to flow in the base-emitter circuit of Q_1 . Therefore, both the signal and oscillator currents flow in the base circuit. Due to the non-linearities of Q_1 , an *IF* signal current exists in the collector circuit. The *IF* transformer, T_2 , transfers the 455 KC *IF* signal to the base of Q_2 , the *IF* amplifier. The collector of Q_2 is terminated into another 455 KC *IF* transformer, T_3 . The secondary is a low impedance winding which drives the crystal detector.

An AGC circuit is used to automatically control the gain of Q_1 and Q_2 . The AGC voltage developed by the detector opposes the bias current of transistors Q_1 and Q_2 , thereby operating them closer to cut-off. To prevent *IF* overloading on large signal strengths, an overload diode is incorporated in the collector circuit of Q_2 . The overload diode is normally biased to cutoff by R_{16} . However, large signal peaks will cause conduction, loading the primary of T_3 . This in turn lowers the stage gain improving the AGC action of the circuit.

The detected audio is *R/C* coupled to the base of the 1st audio amplifier, Q_3 . The collector terminates into the audio interstage transformer, T_4 . Capacitor C_8 rolls off the high frequency response preventing high frequency distortion. The volume control is connected across the low impedance secondary winding of T_4 . It can be seen from this arrangement that the emitter-base bias is unaffected by the setting of the volume control. To prevent the base current from flowing in the secondary of T_4 , capacitor C_9 is used as a *DC* blocking capacitor. The value of the capacitor must be made large for adequate low frequency coupling.

The audio output stage, Q_4 , is a grounded emitter amplifier stage. The collector is terminated into the output transformer, T_5 , whose secondary matches the impedance of the loudspeaker. An earphone jack is provided for private listening. The earphone should have an impedance of approximately 200 ohms.

The power supply consists of a single nine (9) volt mercury cell battery. Used in this circuit the battery has a useful life (intermittent service) of approximately seventy five (75) hours. The battery life is comparatively short since the Class A output stage consumes approximately 11 milliamperes with no signal input.

Portable Radio—The schematic diagram of a transistor portable is shown in Figure 32. This receiver utilizes seven (7) transistors and has an undistorted output of 250 milliwatts. The circuit is of the superheterodyne type consisting of: an oscillator-converter, two stages of *IF* amplification, a crystal diode detector, an *AF* amplifier, an audio driver and a push-pull Class B output stage.

The antenna and input circuits are very similar to the circuit shown in Figure 31. Two *IF*'s are used in this receiver for better selectivity and gain. The output of the crystal detector is fed directly to base-emitter of Q_4 , the 1st *AF* amplifier. A volume control is located in the emitter circuit of Q_4 and the collector is at *AC* ground. This circuit should not be confused with an emitter follower circuit. The common electrode is the emitter and the characteristics are the same as a grounded emitter amplifier.

The driver stage, Q_5 , provides the peak to peak voltages required to drive the push-pull output stage to rated output. The output transistors Q_6 and Q_7 are operated Class B, and a thermistor is used in the base return of both transistors. As the ambient temperature increases, the thermistor decreases in value resulting in a lower bias applied to the base.

In Class B output circuits, the battery current increases with increased signal input. Therefore, prolonged operation at high volume levels will reduce the battery life. The current consumption of this receiver (with no signal) is approximately 8 milliamperes. Therefore, battery life under these conditions is greater than for the previously described radio. However, the current consumption at 50 milliwatts output jumps to 29 milliamperes.

Phonograph Pre-Amplifier—Transistors are ideally suited as phonograph pre-amplifiers for the following reasons: low noise, low hum due to the elimination of heater cathode leakage and no microphonics. A phonograph transistor pre-amplifier is illustrated in Figure 33.

A low impedance *moving coil* type pickup is used to drive the base of the PNP type transistor. Capacitor, C_1 , is required to block the *DC* current from the pickup and also to maintain the proper base biasing. The *B+* voltage from the amplifier's power supply is used to bias the transistor. The emitter terminal voltage averages 6 volts positive in this particular pre-amplifier. The combination of resistors R_1



connected between the base and emitter. Since the collector is grounded, and the output is taken between the emitter and ground, the circuit is a common emitter type. Capacitor C_3 is a decoupling capacitor used to prevent interaction from other circuits using the same B+ supply.

Video Amplifiers—Video output amplifiers differ from audio power amplifiers in that they operate into voltage operated devices such as picture tubes or oscillograph tubes rather than into current operated devices such as loudspeakers. Since transistors are current operated devices they present no problems in audio amplifier applications. However, the fact that the peak to peak driving voltages required by picture tubes are greater than the maximum voltages that can safely be applied to the collectors of most transistors has limited the application of transistors as video output amplifiers in television receivers and similar equipment.

A two stage transistor video amplifier capable of delivering an output of approximately 30 volts peak to peak is shown in Figure 34. The transistors used in this amplifier should have a high frequency cut-off of approximately 30 MC, and the one used in the output stage must have a collector voltage rating of at least 40 volts.



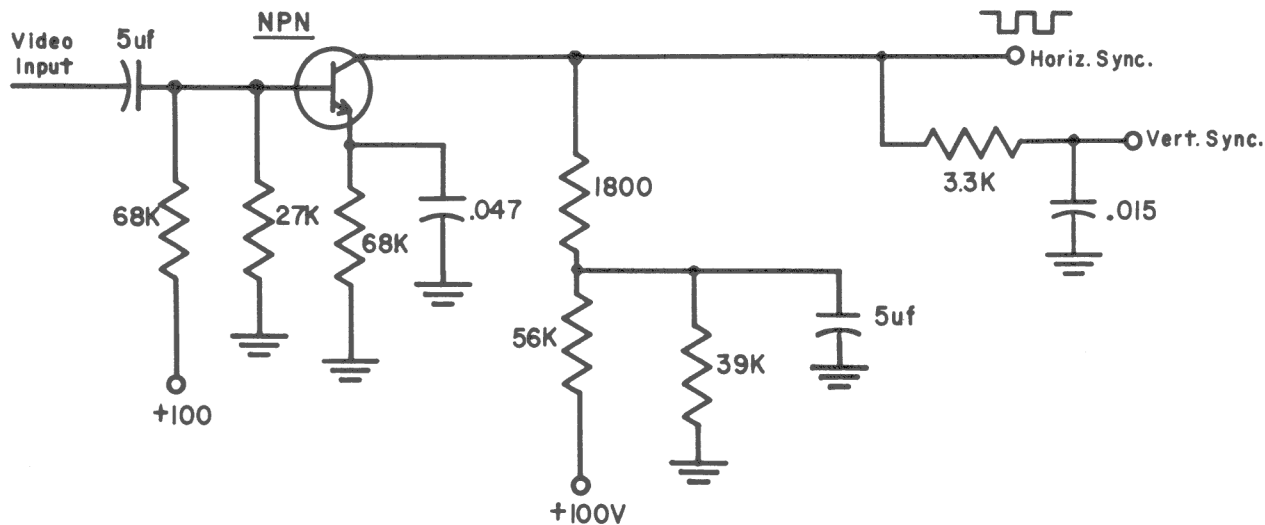


FIGURE 35

The *drift* type transistor which was discussed previously is well suited since it meets both requirements. The base region is thick enough to prevent voltage breakdown and the drift design assures the high frequency response.

As can be seen from Figure 34, both transistors are operated as grounded emitter amplifiers. Series peaking is used at the input of both stages and in the output of the second stage. Also, the emitter resistors are partially bypassed providing additional peaking. This peaking compensates for high frequency losses due to internal and external capacity associated with the transistors. A gain (contrast) control is used in the base circuit of the first stage. The gain of this stage is varied by regulating the base-emitter bias. As the base is made more positive, greater current flows between the emitter and base, thus increasing the stage gain.

A greater output can be obtained from a similar arrangement using a transistor which can operate with higher collector voltages. Another method is to use push-pull output transistors. In this case one transistor drives the cathode of the kinescope while the other transistor simultaneously drives the grid 180° out of phase with the cathode. In this case a Class A push-pull amplifier is used.

Television Sync Separator—A transistor sync separator is shown in Figure 35. In this example a positive voltage supply is available, thus an NPN transistor is used. The transistor is biased such that little current flows without

the presence of signal. When a sync positive video signal is applied to the stage, the developed bias across the resistors in the base circuit produces a clamping action which cuts off the transistor during picture intervals and permits it to conduct only during sync pulse intervals. This dynamic biasing action produces clean, amplified sync pulses at the output of the stage. The gain of the transistor is sufficient to assure that, even on very weak input signals, the collector current saturates and clips off the tips of the sync pulses below the noise level. Horizontal sync pulses are prevented from reaching the vertical sweep circuit by the R/C network in the vertical sync output lead.

Other Transistor Circuits — There are other transistor applications too numerous to cover in this lesson. However, if the technician understands the basic operation of transistor amplifiers and oscillators, little additional reading is necessary to basically understand the operation of a completely transistorized television receiver.

30-8. TRANSISTOR COMPONENTS

Due to the small size of the transistor it is desirable that the associated circuit components be small to allow compact transistorized electronic equipment design. Since the voltage and current requirements are usually low in this type of equipment, resistors, coils, controls, transformers and sockets can be made small in

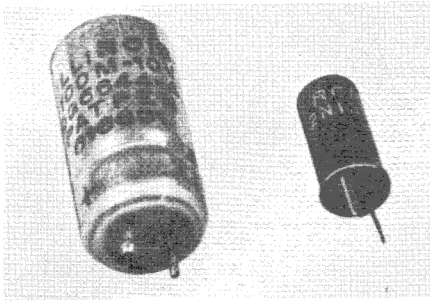


FIGURE 36

size without danger of voltage arc-over and overheating.

Electrolytic Capacitors—The capacitor has presented a different design problem. Due to the low circuit impedances involved, the value of capacitance must be large. Even though the working voltages are low the actual value of capacitance may range from 1 to 100 mf or higher. If ordinary electrolytic capacitors of this value were used in transistor circuits they would be so large that compact design and styling would be impossible.

However, a metal known as *tantalum* overcomes the capacitor size problem. Tantalum is oxidized and this oxide serves as a dielectric. Since tantalum is also used as the capacitor base material, miniature electrolytic capacitors can be made with large capacity values and low working voltages. Such a capacitor is pictured in Figure 36. The case diameter is $\frac{7}{16}$ " and the length is $\frac{3}{4}$ ". It is rated 100 mfd at 10 volts.

Units of lower capacity can be encapsulated in even smaller cases. From the picture in Figure 37 the size of the electrolytic capacitors can be compared to the size of the transistors and other associated parts.

Transformers—The size of a transformer is generally determined by two factors: the

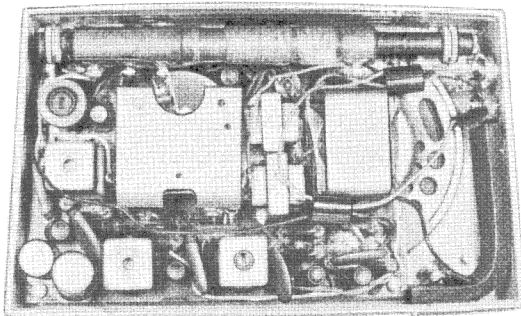


FIGURE 37

amount of unbalanced direct current flowing in the windings and the amount of power to be handled at a specified frequency. If the transformer must handle large *DC* currents the core material must be large to prevent magnetic saturation which in turn will cause distortion of *AC* signal currents. Since the *DC* currents in transistor circuits are usually relatively small, the core material of the transformers can also be made small. However, in some applications, such as audio power amplifiers, the transformer may be as large or larger than those required by electron tube circuits. This is due to the fact that primary currents in the order of 10 amps may be encountered. Generally, *RF*, *IF* and oscillator coils are made small as pictured in Figure 38.

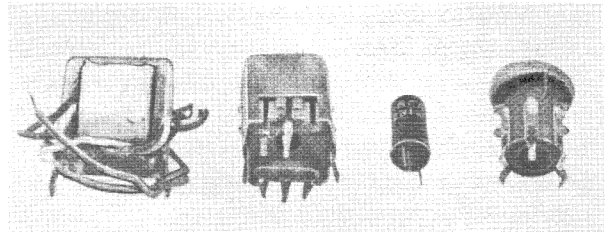


FIGURE 38

3-9. SERVICING TRANSISTOR CIRCUITS

Servicing transistorized electronic equipment presents no major problems when compared with vacuum tube type equipment. With the advent of printed wiring, component parts are neatly arranged with little or no stacking. However, care must be taken to prevent damage of the printed wiring.

One of the outstanding benefits of transistor equipment is the reliability of the transistor itself. Over ninety percent of the failures in electron tube equipment is due to failure of the electron tube. However, transistors have long life and this factor tends to decrease the amount of service required.

Precautions—Although transistors have the advantages of long life and reliability, certain precautions must be observed. Mechanically they are rugged but not indestructible so reasonable care should be employed. The leads are the most fragile part and whether they are the long flexible type or the short rigid type they should be treated in the same manner as the leads of a crystal diode. The transistors with long flexible leads are usually soldered directly into the circuit. When un-soldering or re-soldering, caution should be taken not to

overheat the transistor. As in the case of crystal diodes, long nose pliers should be used to grip the lead between the transistor and point of soldering in order to control the heat. Transistors with short rigid leads are usually plugged into a socket. In some cases, however, these transistors are plugged directly into the printed board and then dip soldered. In this case long nose pliers cannot be used, therefore, the soldering iron should be hot before touching the solder joint and the transistor should be soldered or unsoldered as fast as possible to prevent damage. When un-soldering a component from a transistor socket, the transistor should first be removed to prevent damage from heat.

Due to the low operating voltages required, relatively small voltage changes can greatly upset the biasing of the transistor. Depending on the circuit, small bias changes can result in destruction of the transistor due to excessive transistor dissipation. Therefore, it is important that circuit components are not inadvertently shorted when servicing transistorized equipment.

Servicing Techniques — The actual servicing techniques used when servicing transistor equipment are similar to the techniques used when servicing electron tube circuits. Basically these techniques are:

1. Check Battery
2. Visual Inspection
3. Check Transistor
4. Voltage Check
5. Resistance Check
6. Capacitance Bridging
7. Probing
8. Signal Injection
9. Alignment
10. Component Substitution

Before performing any transistor service, the battery should be checked and direct substitution is generally the best method. However, it is usually best to first check the voltage of the original battery with the receiver on and maximum volume setting. If possible also tune in a strong local station. Generally, where a 9 volt battery is used, the receiver should operate with a battery voltage as low as 6 volts. This, of course, will depend on the design characteristics of a particular receiver. However, circuit trouble should be suspected if the receiver will not operate if the battery voltage is 7.5

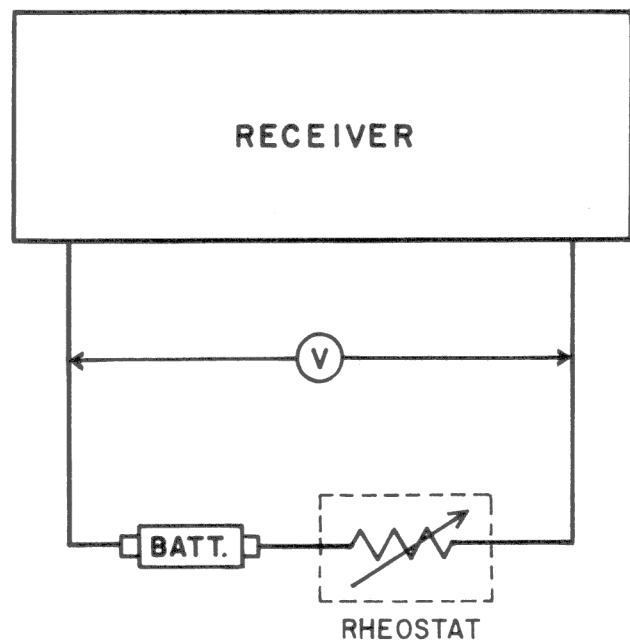


FIGURE 39

to 8 volts. In some cases the customer will complain that batteries only last for a short duration. In all cases an ammeter should be inserted in series with the battery and the total current drain of the receiver measured. These current figures are usually stated in the service notes. If the current reading is high the leakage should be traced and corrected. If not, explain to the customer the operation and limitations of battery operated receivers. It is often desirable to check the operation of the receiver with a reduced battery voltage. This condition can be duplicated by inserting a small resistor in series with the battery. This is shown in Figure 39. The actual value of the resistor used depends on the condition of the battery and the voltage desired. Using a rheostat in this application allows a selection of voltages and allows the technician to check the sensitivity of the receiver under varying voltage conditions. In cases where an AC power supply is used, the supply voltages should be checked before attempting any service work. Improper supply voltages can cause odd effects and many headaches can be eliminated by first checking the power supply.

Visual inspection is also a good service technique. Occasionally a loose wire or faulty connection can be found before extensive voltage checks are made. Faulty components such as burned resistors are seldom encountered since the power of the supply voltage is usually very low.

Transistors, like electron tubes, can be checked by direct substitution. Transistors, however, have a characteristic known as *leakage current* which may affect the results obtained when using the direct substitution method. The leakage current can affect the amplification factor or gain of the transistor and is more critical in certain applications than others. Thus it is possible that a particular transistor will operate satisfactorily in one circuit and not in another. It also has been found that the amount of leakage current will increase slightly as the transistor ages.

Voltage measurements provide a means of checking receiver conditions similar to electron tube circuits. The major difference is the magnitude of the voltages encountered. For example, the bias voltage between the base and emitter is in the order of 0.05 to 0.2 volts. Therefore, a sensitive VTVM is usually required. When making voltage checks the polarity should be observed. In the case of electron tube circuits, if a positive voltage is measured on the grid of a tube a leaky coupling capacitor is indicated. However, in the case of transistors the base to emitter voltage may be positive or negative depending on the type of transistor used. For example, the PNP type normally operates with the base negative with respect to the emitter, whereas, the opposite is true in the case of NPN transistors. The schematic should be checked for the proper polarity as well as the magnitude of the voltage.

In some circuits it may also be desirable to make a current check, although with printed wiring this is not always possible. The amount of current can be calculated by measuring the voltage across a resistor in the circuit and also checking the value of the resistor with an ohmmeter. The current can then be determined with the aid of Ohm's Law. For example, if the collector current is to be measured, measure the voltage drop across the emitter resistor and check the resistor with an ohmmeter. Using Ohm's Law the collector current can be calculated.

Resistance measurements are not generally made in transistor service other than checking

for open circuits in transformers and coils. Due to the low voltage power supplies used in transistor circuits the resistors have little tendency to burn up or change value. It is important that the transistor or component be removed from the circuit before attempting resistance measurements. Since the ohmmeter contains a battery, the wrong polarity voltage may be applied to a critical stage and cause permanent damage to the transistor. Always disconnect supply voltages before removing a transistor from its socket to prevent damage to the transistor by current transients.

Capacitance bridging, probing, and component substitution are all good techniques which are commonly used when servicing electron tube circuits and are equally good when servicing transistor circuits. They are generally resorted to when servicing the so-called "dog" troubles. Care must be taken to observe polarity when substituting or bridging electrolytic capacitors.

Alignment is another excellent service technique when checking *RF* and *IF* stages for sensitivity. A shorted turn in an *RF* or *IF* coil is quickly identified by poor response when tuning the coil. For example, turning the slug in an *IF* coil one-half turn normally has a great effect on the sensitivity of a transistor radio. If this adjustment produces little or no effect the transformer is probably defective or the associated stage inoperative for other reasons.

Signal injection is also an excellent service technique. A defective stage in a radio can be rapidly isolated by injecting a signal at the input to each stage starting at the loud-speaker and moving back to the antenna coil. The defective stage can be identified by a decrease in gain from the previous stage, or by a very slight increase where a large increase should occur.

All of the service techniques mentioned are suitable for all types of transistorized equipment. Keeping in mind the aforementioned precautions, servicing transistor receivers should present no greater problem than their electron tube counterparts.
